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(54) Band-pass filter and duplexer incorporating thin-film bulk acoustic resonators (FBARs)

(57) A band-pass filter comprising shunt elements and series elements in which the series elements and the shunt elements are connected to form a ladder circuit, and each of the elements includes a film bulk acoustic resonator (FBAR). An FBAR-based duplexer comprises a first port, a second port, a third port, a first

FBAR-based band-pass filter as just described connected between the first port and the third port and a series circuit connected between the second port and the third port. The series circuit includes a 90° phase shifter in series with a second FBAR-based band-pass filter as just described.

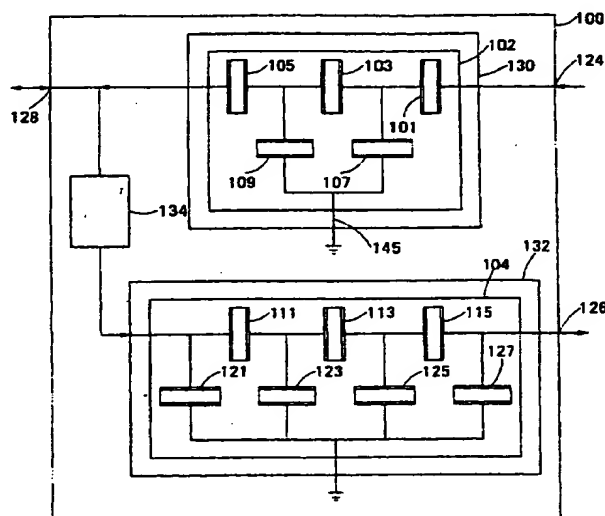


FIG.4

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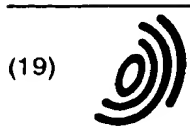
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EUROPEAN SEARCH REPORT

Application Number
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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	EP 0 880 227 A (NOKIA MOBILE PHONES LTD) 25 November 1998 (1998-11-25)	1	H03H9/58
A	* page 22, line 25 - page 23, line 41; figures 13-18B *	8	
X	SEABURY C W ET AL: "THIN FILM ZNO BASED BULK ACOUSTIC MODE FILTERS" 1997 IEEE MTT-S INTERNATIONAL MICROWAVE SYMPOSIUM DIGEST. DENVER, JUNE 8 - 13, 1997, IEEE MTT-S INTERNATIONAL MICROWAVE SYMPOSIUM DIGEST, NEW YORK, NY: IEEE, US, vol. 1, 8 June 1997 (1997-06-08), pages 181-184, XP000767186 ISBN: 0-7803-3815-4	1	
A	* page 183, left-hand column, line 10 - right-hand column, line 25; figure 8 *	6,7,9, 10,13	
A	DE 195 31 996 A (SIEMENS AG) 6 March 1997 (1997-03-06) * column 2, line 10 - column 3, line 17; figures *	8	
X	US 5 294 862 A (BANNO HISAO ET AL) 15 March 1994 (1994-03-15) * column 3, line 4 - column 4, line 41 *	1,2,4	TECHNICAL FIELDS SEARCHED (Int.Cl.7) H03H
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 21 September 2001	Examiner D/L PINTA BALLE..., L
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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(54) **Band-pass filter and duplexer incorporating thin-film bulk acoustic resonators (FBARs)**

(57) A band-pass filter comprising shunt elements and series elements in which the series elements and the shunt elements are connected to form a ladder circuit, and each of the elements includes a film bulk acoustic resonator (FBAR). An FBAR-based duplexer comprises a first-port, a second-port, a third-port, a first FBAR-based band-pass filter as just described connected between the first port and the third port and a series circuit connected between the second port and the third port. The series circuit includes a 90° phase shifter in series with a second FBAR-based band-pass filter as just described.

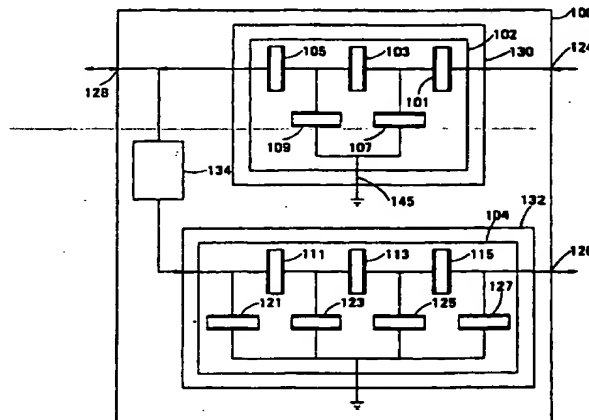


FIG.4

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transmitter 14 can deliver up to 1 Watt of power to the transmit port 24 of the duplexer 20. Miniaturized as just described, the band-pass filters 30 and 32 must be capable of transmitting such power without being destroyed, or without its characteristics degrading with use.

[0010] Current-generation PCS devices use a ceramic filter as the duplexer 20. However, such ceramic filters are bulky, measuring some $28 \times 8 \times 5$ mm, are over-height components and are expensive. Samples of such filters show evidence of having been individually tuned, which accounts for some of the cost of such devices.

[0011] Surface acoustic wave (SAW) filters have also been used as duplexers in cellular telephones and PCS devices, see, for example, O. Ikata, N. Nishihara, Y. Satoh, H. Fukushima and N. Hirisawa, *A Design of Antenna Duplexer Using Ladder Type SAW Filters*, PROC. 1998 IEEE INTERNATIONAL ULTRASONICS SYMPOSIUM, SENDAI, JAPAN, paper O-1 (Oct. 1998). The roll-off of a SAW filter with sufficient power handling capability is insufficiently steep for the CDMA application just described. Instead, two SAW filters and an electronic switch have to be used. One of the filters covers the upper half of the transmit and receive bands, the other covers the lower half of the transmit and receive bands. The electronic switch selects the appropriate filter depending on the portions of the transmit and receive bands in which the PCS device is operating. Thus, a duplexer based on SAW filters is also unacceptable bulky, complex, expensive and may be subject to failure in the event of a surge in the transmitter output power.

[0012] What is needed, then, is a duplexer that has sufficiently steep filter characteristics to enable it to be used in applications, such as CDMA PCS devices, in which the separation between the transmit and receive bands is only about 1% of the operating frequency and in which power levels exceeding one Watt do not impair the reliability of the duplexer or the long-term stability of the filter characteristics. The duplexer should be substantially smaller than current duplexers based on ceramic filters or SAW filters, and should not require individual tuning so that the cost of manufacture can be kept low.

Summary of the Invention

[0013] The invention provides a band-pass filter comprising shunt elements and series elements in which the series elements and the shunt elements are connected to form a ladder circuit, and each of the elements includes an FBAR.

[0014] The FBARs may collectively have two different resonant frequencies.

[0015] The FBARs may collectively have more than two different resonant frequencies.

[0016] The FBARs may all have different resonant

frequencies.

[0017] The FBARs comprised in the series elements may all have the same resonant frequency, and the FBARs comprised in the shunt elements may also all have the same resonant frequency, different from the resonant frequency of the FBARs comprised in the series elements.

[0018] At least one of the elements may additionally comprise an auxiliary inductor in series with the FBAR comprised therein.

[0019] The invention also provides an FBAR-based duplexer that comprises a first port, a second port, a third port, a first band-pass filter according to the invention connected between the first port and the third port and a series circuit connected between the second port and the third port. The series circuit includes a 90° phase shifter in series with a second band-pass filter according to the invention.

[0020] At least one of the elements of the band-pass filters may additionally comprise an auxiliary inductor in series with the FBAR comprised therein.

[0021] The FBAR with the auxiliary inductor in series includes a shunt capacitance, and the auxiliary inductor has an inductance that has a series resonance with the shunt capacitance at a frequency corresponding to the upper band limit of the first band-pass filter, the lower band limit of the first band-pass filter, the upper band limit of the second band-pass filter, or the lower band limit of the second band-pass filter.

[0022] Finally, the invention provides an integrated array of film bulk acoustic resonators (FBARs) in which at least one of the FBARs differs in resonant frequency from others of the FBARs. The integrated array comprises a piezoelectric layer including a first major surface opposite a second major surface. The integrated array additionally comprises first electrodes located on the first major surface of the piezoelectric layer, and second electrodes located on the second major surface of the piezoelectric layer. One of the FBARs is defined at each of the locations where one of the second electrodes overlaps one of the first electrodes. The electrodes that define the one of the FBARs that differs in resonant frequency from the others of the FBARs differ in weighted thickness from others of the electrodes defining the others of the FBARs.

Brief Description of the Drawings

[0023]

Figure 1 is a block diagram showing the front-end circuit 10 of a conventional cellular telephone, personal communication system (PCS) device or other transmit/receive apparatus.

Figure 2 is a graph showing the basic arrangement of the transmit and receive bands of a CDMA PCS device and the required characteristics of the transmit and receive band-pass filters constituting the

first working embodiment 100 of a duplexer according to the invention that incorporates the transmit FBAR array 102 and the receive FBAR array 104. The duplexer 100 is a three-port device suitable for use in a CDMA PCS device and including a transmit port 124, a receive port 126 and an antenna port 128. The duplexer is composed of the 90° phase shifter 134, the transmit band-pass filter 130 that includes the transmit FBAR array 102 and the receive band-pass filter 132 that includes the receive FBAR array 104. The transmit port is connected to the antenna port through the transmit band-pass filter 130. The antenna port is connected to the receive port through the series arrangement of the 90° phase shifter 134 and receive band-pass filter 132.

[0031] When used in a PCS device, cellular telephone or other transmit/receive apparatus, the antenna port 128 of the duplexer 100 is connected to an antenna (not shown), transmit port 124 is connected to the output of a transmitter (not shown) and the receive port 126 is connected to the input of a receiver (not shown) in a circuit arrangement similar to that shown in Figure 1A. The pass bands of the band-pass filters 130 and 132 are respectively centered on the frequency range of the transmit signal generated by the transmitter and that of the receive signal to which the receiver can be tuned. In the example shown, the transmit and receive band-pass filters 130 and 132 are configured such that the high-frequency stop band of the transmit band-pass filter 130 that includes the transmit FBAR array 102 overlaps the pass-band of the receive band-pass filter 132 that includes the receive FBAR array 104 and the low-frequency stop band of the receive band-pass filter overlaps the pass-band of the transmit band-pass filter.

[0032] The structure of the transmit band-pass filter 130 will now be described. The transmit band-pass filter is composed of the transmit FBAR array 102. The transmit FBAR array is composed of the series FBARs 101, 103 and 105 and the shunt FBARs 107 and 109 connected to form a ladder circuit. The series FBARs are connected in series between the transmit port 124 and the antenna port 128, the shunt FBAR 107 is connected between ground and the node between the series FBARs 101 and 103 and the shunt FBAR 109 is connected between ground and the node between the series FBARs 103 and 105. Thus, in the example shown, the FBARs 101, 103, 105, 107 and 109 form a 2½-stage ladder circuit. However, the number of stages in the ladder circuit is not critical to the invention. The number of full stages, each composed of one series FBAR and one shunt FBAR, and the number of half stages, each composed of one series FBAR or one shunt FBAR, in the FBAR array 102 depends on the desired filter characteristics of the transmit band-pass filter 130 and the characteristics of the individual FBARs constituting the transmit FBAR array 102. For example, in one preferred embodiment, the transmit band-pass filter is a two-stage filter that lacks the FBAR 105.

[0033] The structure of the receive band-pass filter

132 will now be described. The receive band-pass filter is composed of the receive FBAR array 104. The receive FBAR array is composed of the series FBARs 111, 113 and 115 and the shunt FBARs 121, 123, 125 and 127 connected to form a ladder circuit. The series FBARs are connected in series between the end of the 90° phase shifter 134 remote from the antenna port 128 and the receive port 126. The shunt FBAR 121 is connected between ground and the node between the series FBAR 111 and the end of the 90° phase shifter 134 remote from the antenna port 128. The shunt FBAR 123 is connected between ground and the node between the series FBARs 111 and 113, the shunt FBAR 125 is connected between ground and the node between the series FBARs 113 and 115 and the shunt FBAR 127 is connected between ground and the node between the series FBAR 115 and the receive port 126. Thus, in the example shown, the FBARs 111, 113, 115, 121, 123, 125 and 127 form a 3½-stage ladder circuit. However, the number of stages in the ladder circuit is not critical to the invention. The number of full stages and the number of half stages required depends on the desired filter characteristics of the receive band-pass filter 132 and the characteristics of the individual FBARs constituting the receive FBAR array 104.

[0034] Circuits suitable for use as the 90° phase shifter 134 are known in the art. For example, the 90° phase shifter may be composed of lumped inductors and capacitors or a $\lambda/4$ transmission line.

[0035] To design the FBAR arrays 102 and 104 to provide the desired filter characteristics of the transmit and receive band-pass filters 130 and 132, respectively, the inventors used a commercial microwave design simulator called *Microwave Design System* (MDS), release 7.0 (1996), sold by HP EEsof Corp., Westlake Village, CA. The individual FBARs of each FBAR array were modeled using the modified Butterworth-Van Dyke circuit shown in Figure 3B. The design simulator was used to optimize the area and to calculate the required resonant frequencies of the FBARs in each of the FBAR arrays 102 and 104. The inventors used a physical simulator to model the piezoelectric resonator stack (shown at 62 in Figure 3A) of each FBAR, to characterize the physical properties of the layers constituting the piezoelectric resonator stack and to calculate the thickness of the layers of the piezoelectric resonator stack constituting each FBAR to achieve the required resonant frequencies. The simulator was written in *Mathcad 8*, sold by MathSoft, Inc., Cambridge, MA, and was based on the model described by W.P. Mason in *PHYSICAL ACOUSTICS PRINCIPLES AND METHODS*, Vol. 1A, pp. 239-247, Academic Press, New York (1964).

[0036] To provide the desired filter characteristics of the transmit band-pass filter 130 in the duplexer 100 of a CDMA PCS device, the series FBARs 101-105 constituting the transmit FBAR array 102 can all have the same resonant frequency and the shunt FBARs 107 and 109 can both have the same resonant frequency.

the shunt FBARs. The process required to fabricate an integrated FBAR array in which the series FBARs all have the same resonant frequency and the shunt FBARs all have the same resonant frequency, different from that of the series FBARs, is only slightly more complex than that required to fabricate an integrated FBAR array in which all the FBARs have the same resonant frequency.

[0048] In an embodiment of the integrated FBAR array 70 for use in embodiments of the FBAR arrays 102 and 104 in which the FBARs collectively have more than two resonant frequencies, such as an embodiment of the receive FBAR array 104 for use in the duplexer of a CDMA PCS device, the electrodes of the FBARs have different thicknesses corresponding in number to the number of different resonant frequencies. Fabricating embodiments of the integrated FBAR array for use as the receive FBAR array 104 in the duplexer of a CDMA PCS device, in which the electrodes collectively have more than two different thicknesses, and may have thicknesses corresponding in number to the number of FBARs in the array, is a complex task using present-day integrated FBAR array fabrication techniques. However, fabricating the receive FBAR array in this manner minimizes the size of the duplexer 100, since the duplexer 100 is composed of only of the two FBAR arrays 102 and 104 and the 90° phase shifter 134. Figure 6 is a schematic block diagram of a second embodiment 200 of a duplexer according to the invention. Compared with the embodiment shown in Figure 4, this embodiment is somewhat larger, but its receive FBAR array 204 is easier and lower in cost to manufacture using present-day integrated FBAR array fabrication techniques. The duplexer 200 has filter characteristics that makes it suitable for use as the duplexer of a CDMA PCS device, yet both the transmit FBAR array 202 and the receive FBAR array 204 are each composed of series FBARs all having the same resonant frequency and shunt FBARs all having the same resonant frequency, different from that of the series FBARs. This enables an integrated FBAR array in which the FBARs collectively have only two resonant frequencies to be used as each of the FBAR arrays 202 and 204. Such integrated FBAR arrays can be fabricated by a process that is little more complex than that for fabricating FBAR arrays in which the FBARs all have the same resonant frequency. Elements of the duplexer 200 shown in Figure 6 that correspond to elements of the duplexer shown in Figure 4 are indicated using the same reference numerals and will not be described again here.

[0049] The duplexer 200 is a three-port device having a transmit port 124, a receive port 126 and an antenna port 128 and is composed of the 90° phase shifter 134, the transmit band-pass filter 230 that includes the transmit FBAR array 202 and the receive band-pass filter 232 that includes the receive FBAR array 204. The transmit port is connected to the antenna port through the transmit band-pass filter. The antenna

port is connected to the receive port through the series arrangement of the 90° phase shifter and the receive band-pass filter.

[0050] When used in a PCS device, cellular telephone or other transmit/receive apparatus, the antenna port 128 of the duplexer 200 is connected to an antenna (not shown), the transmit port 124 is connected to the output of a transmitter (not shown) and the receive port 126 is connected to the input of a receiver (not shown) in a circuit arrangement similar to that shown in Figure 1A. The pass bands of the band-pass filters 230 and 232 are respectively centered on the frequency range of the transmit signal generated by the transmitter and that of the receive signal to which the receiver can be tuned. In the example shown, band-pass filters 230 and 232 are configured such that the high-frequency stop band of the transmit band-pass filter 230 overlaps the pass-band of the receive band-pass filter 232 and the low-frequency stop band of the receive band-pass filter overlaps the pass-band of the transmit band-pass filter.

[0051] The receive band-pass filter 232 will now be described. The receive band-pass filter is composed of the receive FBAR array 204, the series auxiliary inductors 241 and 243 and the shunt auxiliary inductors 231, 233, 235 and 237. The receive FBAR array is composed of the series FBARs 211, 213 and 215 and the shunt FBARs 221, 223, 225 and 227 connected to form a ladder circuit. The series auxiliary inductor 241, the series FBARs 211, 213 and 215 and the series auxiliary inductor 243 are connected in series between end of the 90° phase shifter 134 remote from the antenna port 128 and the receive port 126. The shunt FBAR 221 and the shunt auxiliary inductor 231 are connected in series between ground and the node between the series auxiliary inductor 241 and the series FBAR 211. The shunt FBAR 223 and the shunt auxiliary inductor 233 are connected in series between ground and the node between the series FBARs 211 and 213. The shunt FBAR 225 and the shunt auxiliary inductor 235 are connected in series between ground and the node between the series FBARs 213 and 215. The shunt FBAR 227 and the shunt auxiliary inductor 237 are connected in series between ground and the node between the series FBAR 215 and the series auxiliary inductor 243. Thus, in the example shown, the FBARs and the auxiliary inductors are connected to provide a 3½-stage ladder circuit. However, the number of stages in the ladder circuit is not critical to the invention. The number of full stages and the number of half stages required depends on the desired filter characteristics of the receive band-pass filter 232, the characteristics of the individual FBARs constituting the receive FBAR array 204 and the characteristics of the auxiliary inductors.

[0052] In the FBAR array 204, the series FBARs 211, 213 and 215 all have the same resonant frequency and the shunt FBARs 221, 223, 225 and 227 all have the same resonant frequency. In the example shown, the resonant frequency of the series FBARs is about

The shunt FBAR 209 and the shunt auxiliary inductor 243 are connected in series between ground and the node between the series FBARs 203 and 205. Thus, in the example shown, the FBARs and the auxiliary inductors are connected to provide a 2½-stage ladder circuit.

[0062] The number of stages in the ladder circuit of the transmit band-pass filter 230 is not critical to the invention. The number of full stages and the number of half stages required depends on the desired filter characteristics of the transmit band-pass filter, the characteristics of the individual FBARs constituting the receive FBAR array 202 and the characteristics of the auxiliary inductors. In one preferred embodiment, the transmit filter is composed of a two-stage ladder circuit that lacks the series FBAR 205.

[0063] The effects of the auxiliary inductors on the filter characteristics of the transmit band-pass filter 230 correspond to the above-described effects of the auxiliary inductors on the filter characteristics of the transmit array and will therefore not be described in detail.

[0064] As an alternative to connecting an auxiliary inductor in series with each of the shunt FBARs 207 and 209 of the transmit band-pass filter 230, a single auxiliary inductance may be in series with the common ground path 245 of the shunt FBARs 107 and 109. Connecting a single auxiliary inductance as just described increases the above-band rejection and degrades the below-band rejection of the transmit band-pass filter. Auxiliary inductors connected in series with both shunt FBARs, as shown in Figure 6, increase both the above-band and below-band rejections.

[0065] In a prototype embodiment of the duplexer 200 shown in Figure 6, the insertion loss between the transmit port 124 and the antenna port 128 was less than 3 dB over most of the transmit band. The isolation from the transmit port 124 to the receive port 126 was greater than 50 dB across most of the transmit band and was greater than 46 dB across the receive band.

[0066] The band-pass filters 230 and 232 constituting the duplexer 200 consistently have a power handling capability of 2 Watts C.W. across the transmit band.

[0067] The measured characteristics of the prototype FBAR-based duplexer according to the invention meet or exceed many of the specifications of the CDMA PCS 1,900 MHz ceramic resonator duplexer described by T. Okada, T. Tsujiguchi, and H. Matsumoto in *A Miniaturized Dielectric Monoblock Duplexer for 1.9 GHz Band PCS Telephone System*, 96 IEIC TECH. REPORT, IEICE, no. 349, (CPMG 96-103), pp. 55-60, (1996). The package dimensions of the prototype FBAR-based duplexer were about 8 mm × 5 mm × 2 mm, so that the volume of the prototype FBAR-based duplexer was about 1/14 that of the above-mentioned ceramic duplexer. More importantly, the height of the prototype FBAR-based duplexer was about one-third of that of the ceramic duplexer so that the FBAR-based duplexer is no longer the tallest component on the printed circuit board. This is advantageous in thin

form-factor applications such as the handsets of PCS devices, cellular telephones or cordless telephones.

[0068] SAW duplexers have approximately the same size as that of the prototype FBAR-based duplexer according to the invention, but SAW technology has yet to achieve the power handling capabilities and high Q needed to meet the roll-off requirements of the CDMA PCS 20 MHz guard band. Consequently, as noted above, more than one SAW filter has to be used to obtain the required characteristics. This imposes a commensurate increase in the volume of the duplexer.

[0069] In an FBAR-based duplexer according to the invention, the area of the FBARs constituting the respective FBAR arrays determine the characteristic impedance of the duplexer. The characteristic impedance of the duplexer has to be matched to the characteristic impedance of the antenna. The characteristic impedance of the antenna is typically 50 Ω. Designing the receive FBAR array 204 for a characteristic impedance of 50 Ω results in the shunt FBAR 227 adjacent the receive port 126 being substantially smaller in size than the shunt FBARs 223 and 225, and the shunt FBAR 221 adjacent the 90° phase shifter 134 being smaller in size than the shunt FBARs 223 and 225. The smaller size of the shunt FBAR 227 causes it to have a substantially smaller Q than the remaining shunt FBARs. The smaller Q of the FBAR 227 degrades the filter characteristics of the receive band-pass filter 232.

[0070] Figure 7 shows a third embodiment 300 of a duplexer according to the invention. In this embodiment, the receive band-pass filter 332 has a characteristic impedance of 50 Ω, yet the shunt FBAR 337 of the receive FBAR array 304 is composed of elements that are comparable in size and in Q with the shunt FBARs 233 and 235. Elements of the duplexer 300 shown in Figure 7 that correspond to elements of the duplexers shown in Figures 5 and 6 are indicated using the same reference numerals and will not be described again here.

[0071] In the duplexer 300, the shunt impedance is kept about the same as that of the FBAR 227 and the Q is improved by using the series arrangement of the two FBARs 351 and 353 that have approximately twice the area of the single FBAR. Thus, the FBARs 351 and 353 have twice the area of FBARs 223 and 225, and have higher Qs. As a result, an embodiment of the duplexer 300 having a 50 Ω characteristic impedance has filter characteristics that are better than those of an embodiment of the duplexer 200 having a 50 Ω characteristic impedance. The series arrangement of the FBARs 351 and 353 also tolerates four times more power than the single FBAR 227.

[0072] A further improvement in the filter characteristics of the duplexer 300 is preferably obtained by using the series arrangement of the two FBARs 355 and 357 as the FBAR 321 instead of a single, small-area FBAR.

[0073] Although the series-connected FBARs 351 and 353 and 355 and 357 are described above as being

1-7.

9. The duplexer of claim 8, in which at least one of the elements additionally comprises an auxiliary inductor in series with the FBAR comprised therein. 5

10. The duplexer of claim 9, in which:

the first band-pass filter and the second band-pass filter each have an upper band limit and a lower band limit, one of the upper band limit and the lower band limit of the first band-pass filter overlapping the other of the upper band limit and the lower band limit of the second band-pass filter; 10 15

the FBAR includes a shunt capacitance; and the auxiliary inductor has an inductance that has a series resonance with the shunt capacitance at a frequency corresponding to one of the upper band limit and the lower band limit of the first band-pass filter and the upper band limit and the lower band limit of the second band-pass filter. 20

11. The duplexer of claim 9 or 10, in which the auxiliary inductor is in series with the FBAR comprised in one of the shunt elements. 25

12. The duplexer of claim 11, in which the one of the shunt elements is one of the shunt elements of the second band-pass filter. 30

13. An integrated array of film bulk acoustic resonators (FBARs) in which at least one of the FBARs differs in resonant frequency from others of the FBARs, the integrated array comprising: 35

a piezoelectric layer comprising a first major surface opposite a second major surface; first electrodes located on the first major surface of the piezoelectric layer; and 40 second electrodes located on the second major surface of the piezoelectric layer, one of the FBARs being defined at locations where one of the second electrodes overlaps one of the first electrodes, in which: 45

the electrodes that define the one of the FBARs differing in resonant frequency from the others of the FBARs differ in weighted thickness from others of the electrodes defining the others of the FBARs. 50

14. The integrated array of claim 13, in which the electrodes defining the one of the FBARs differing in resonant frequency from the others of the FBARs differ in physical thickness from the others of the electrodes. 55

15. The integrated array of claim 13 or 14, in which:

the FBARs constitute series and shunt elements of a ladder circuit; the electrodes of the FBARs constituting the series elements have substantially the same weighted thickness; and the electrodes of the FBARs constituting the shunt elements have substantially the same weighted thickness, different from the weighted thickness of the electrodes of the FBARs constituting the series elements.

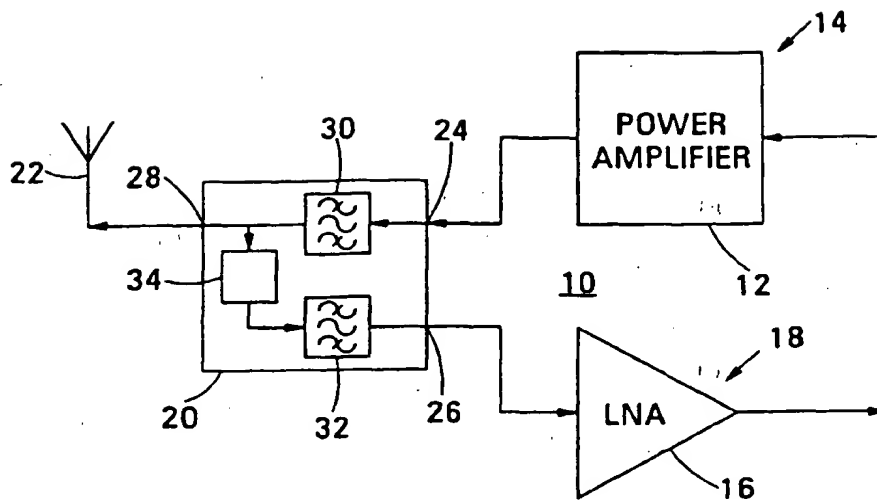


FIG.1

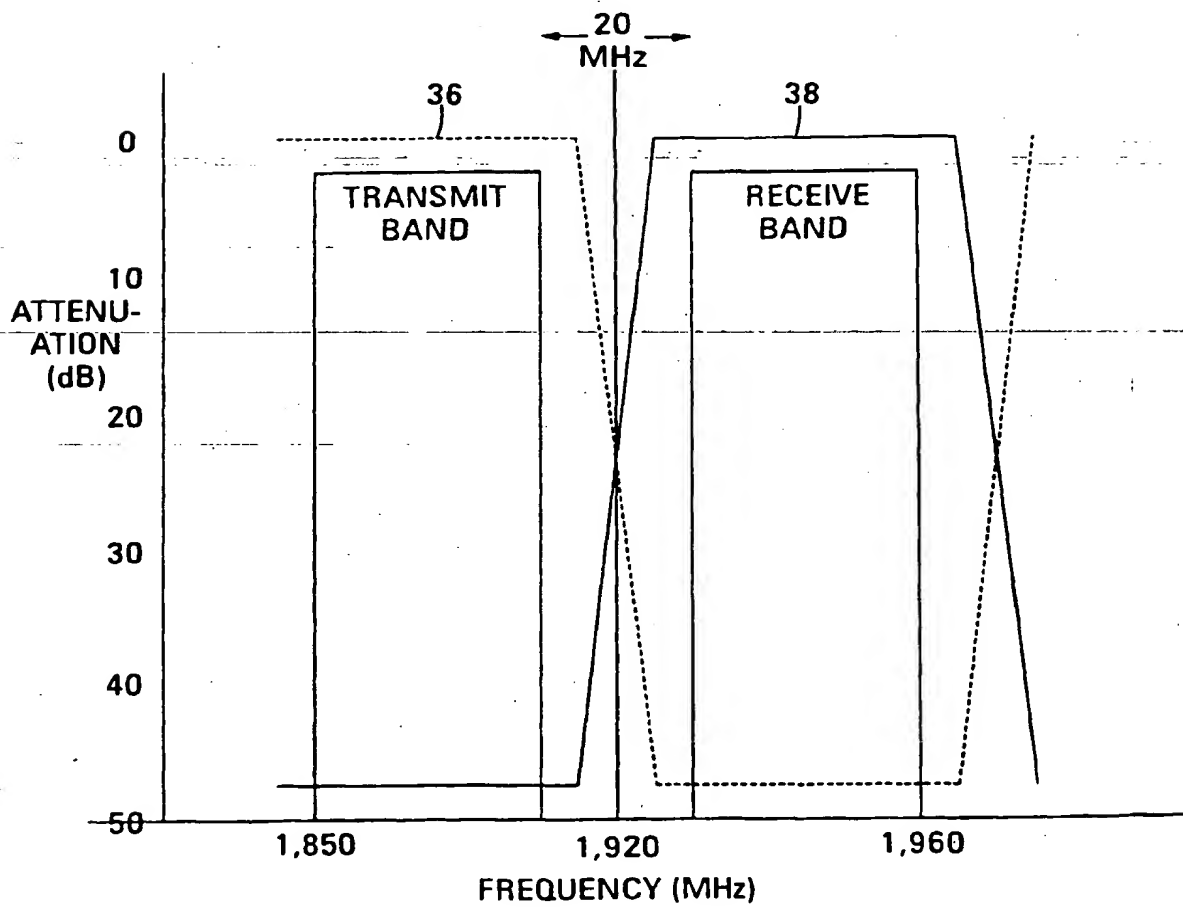


FIG.2

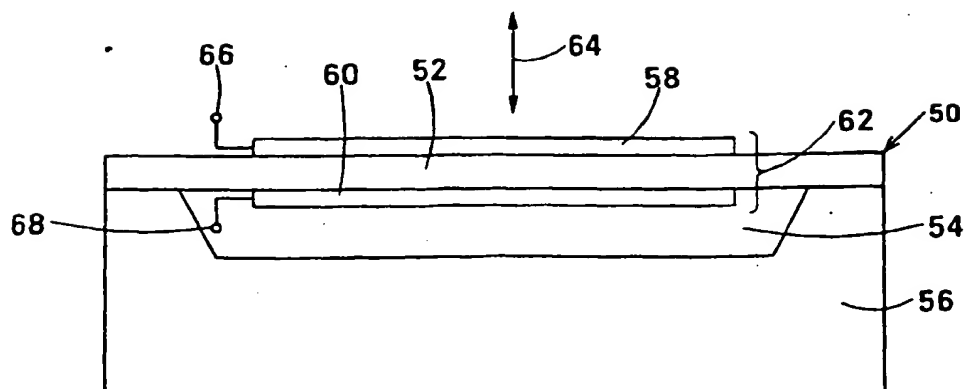


FIG.3A

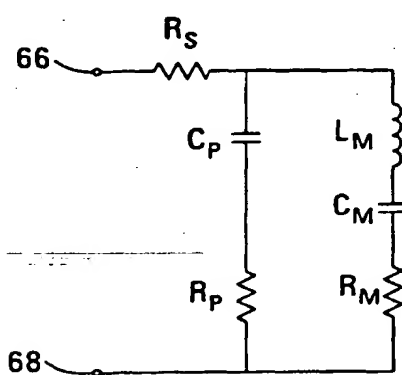


FIG.3B

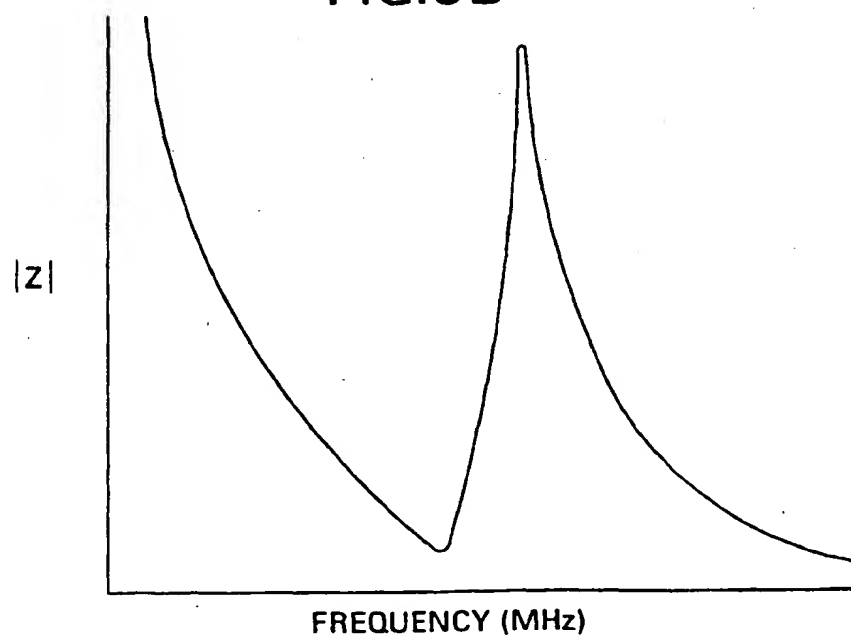


FIG.3C

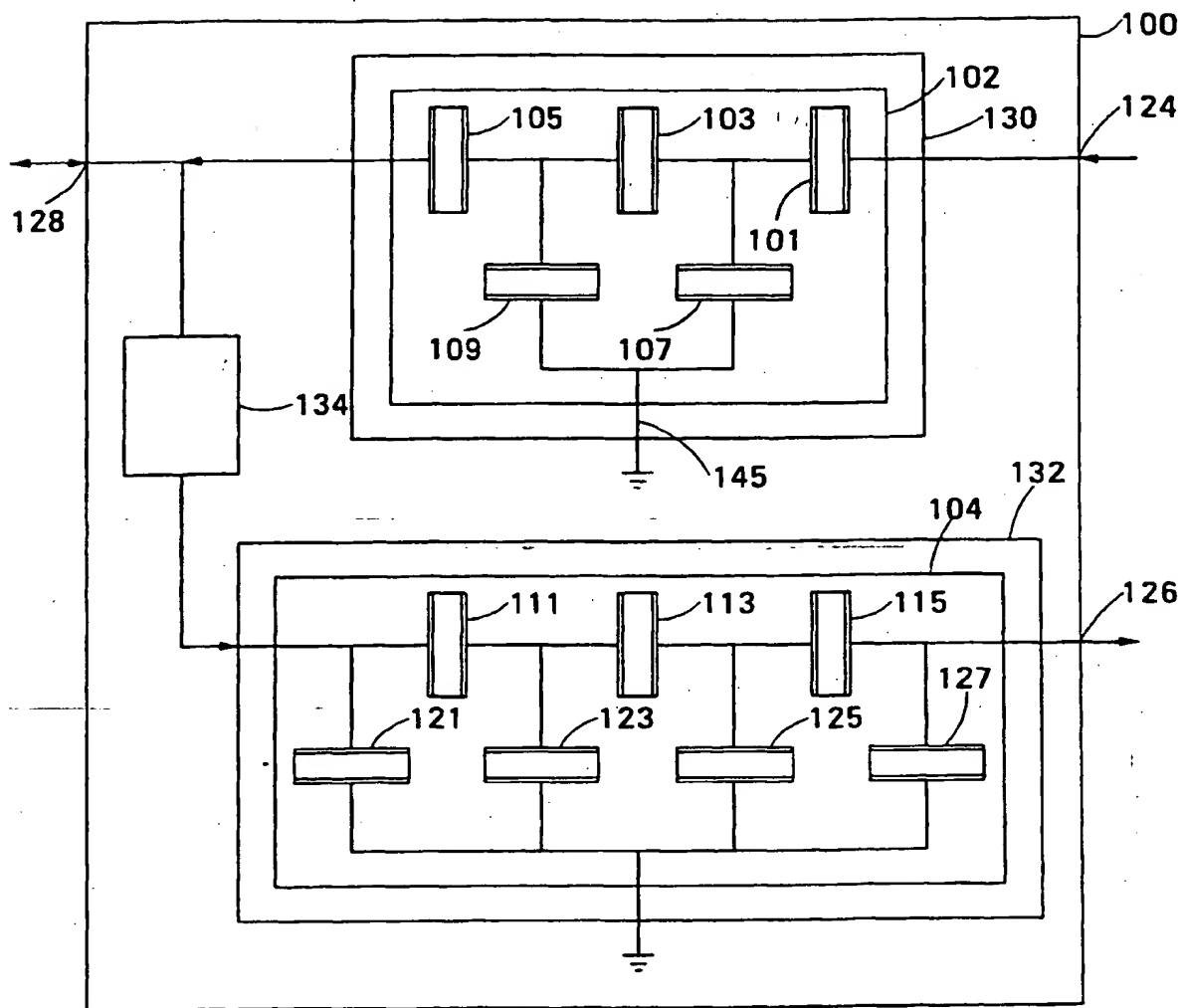


FIG.4

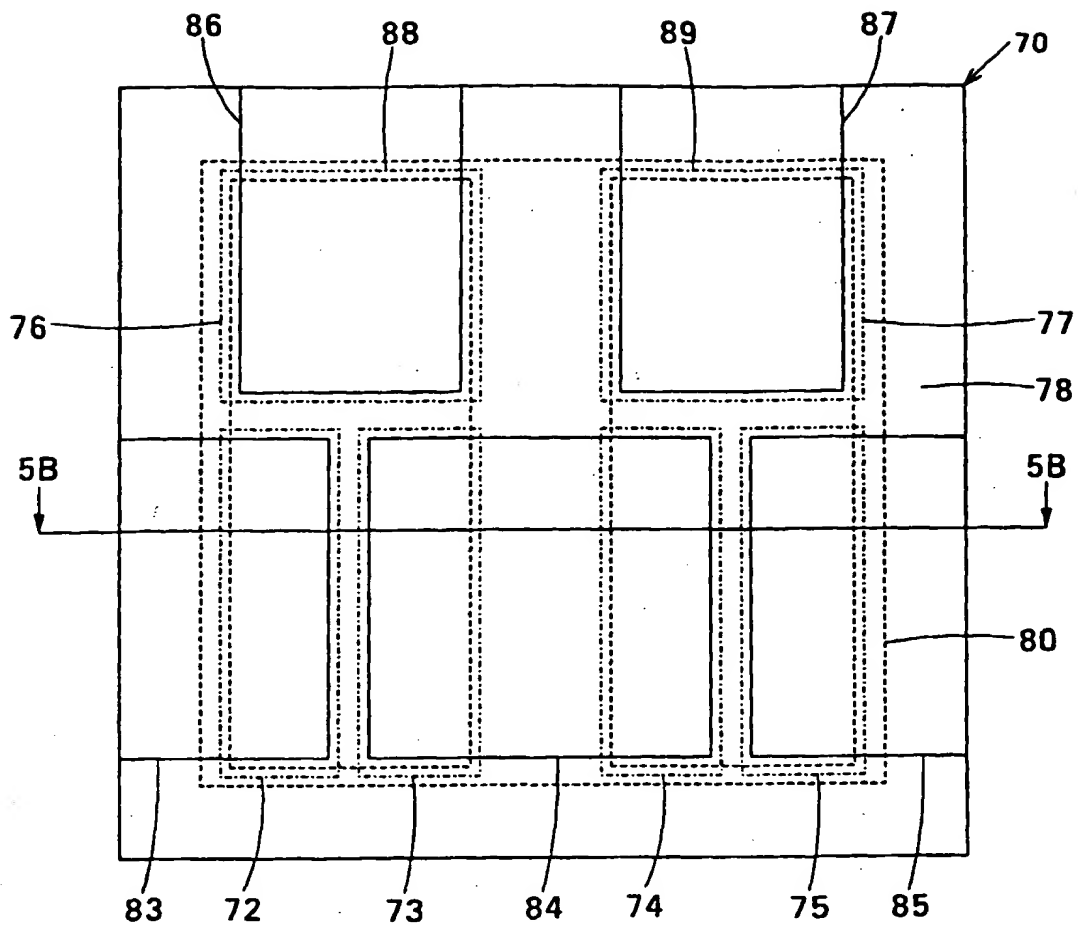


FIG. 5A

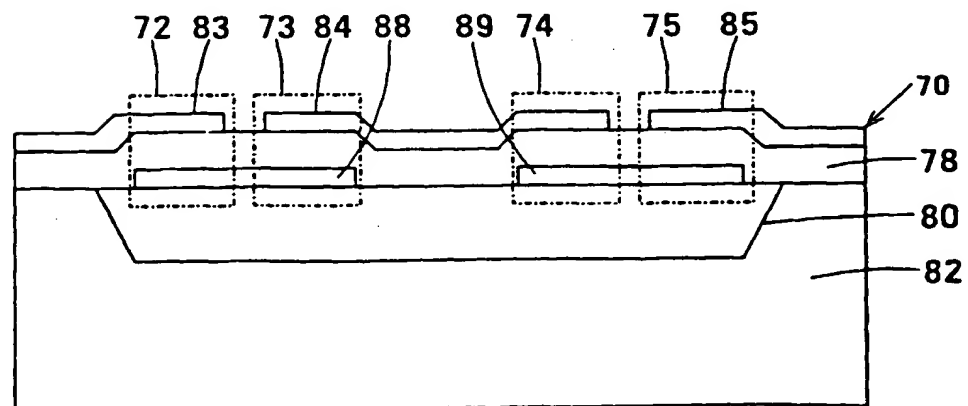


FIG. 5B

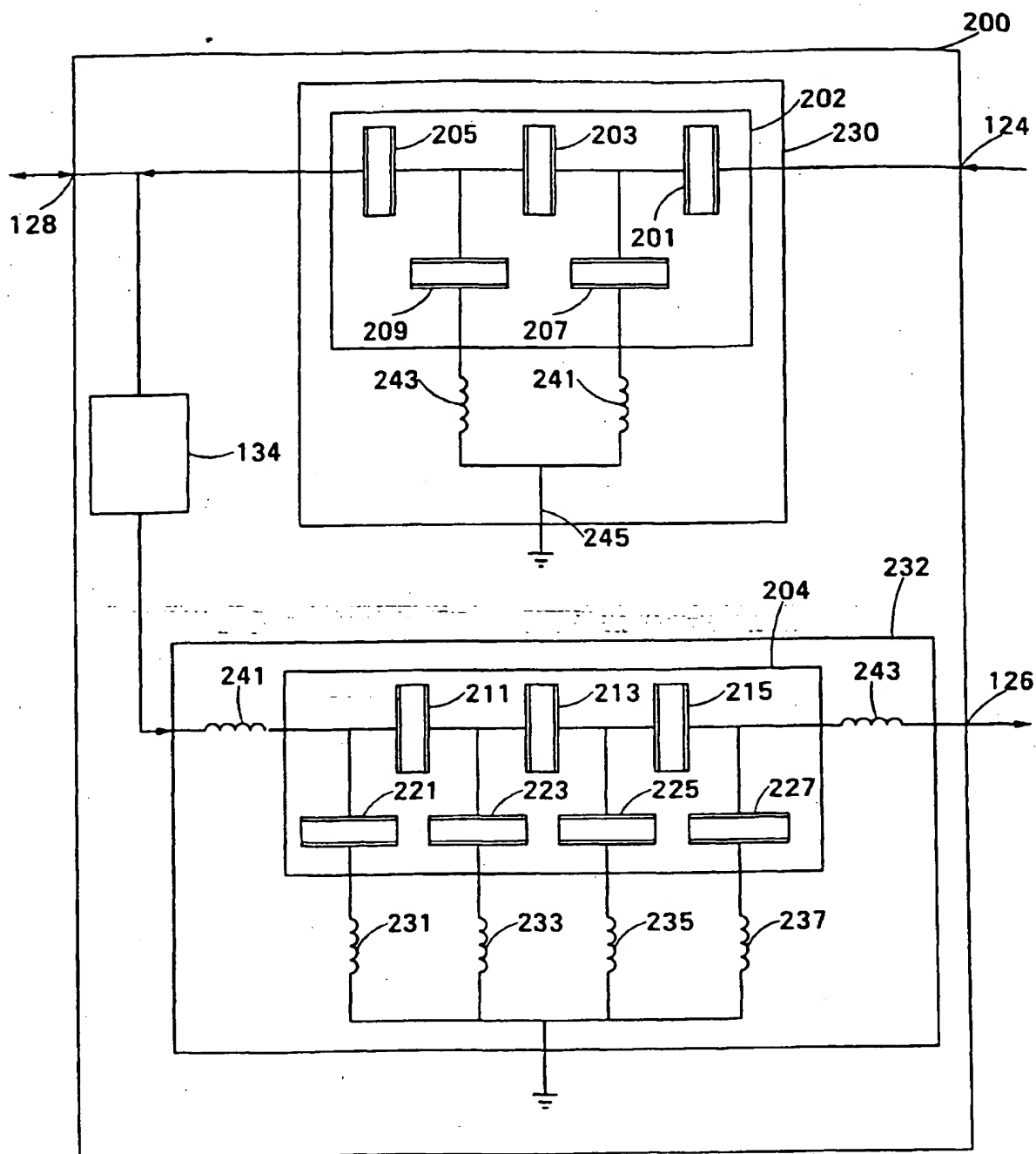


FIG.6

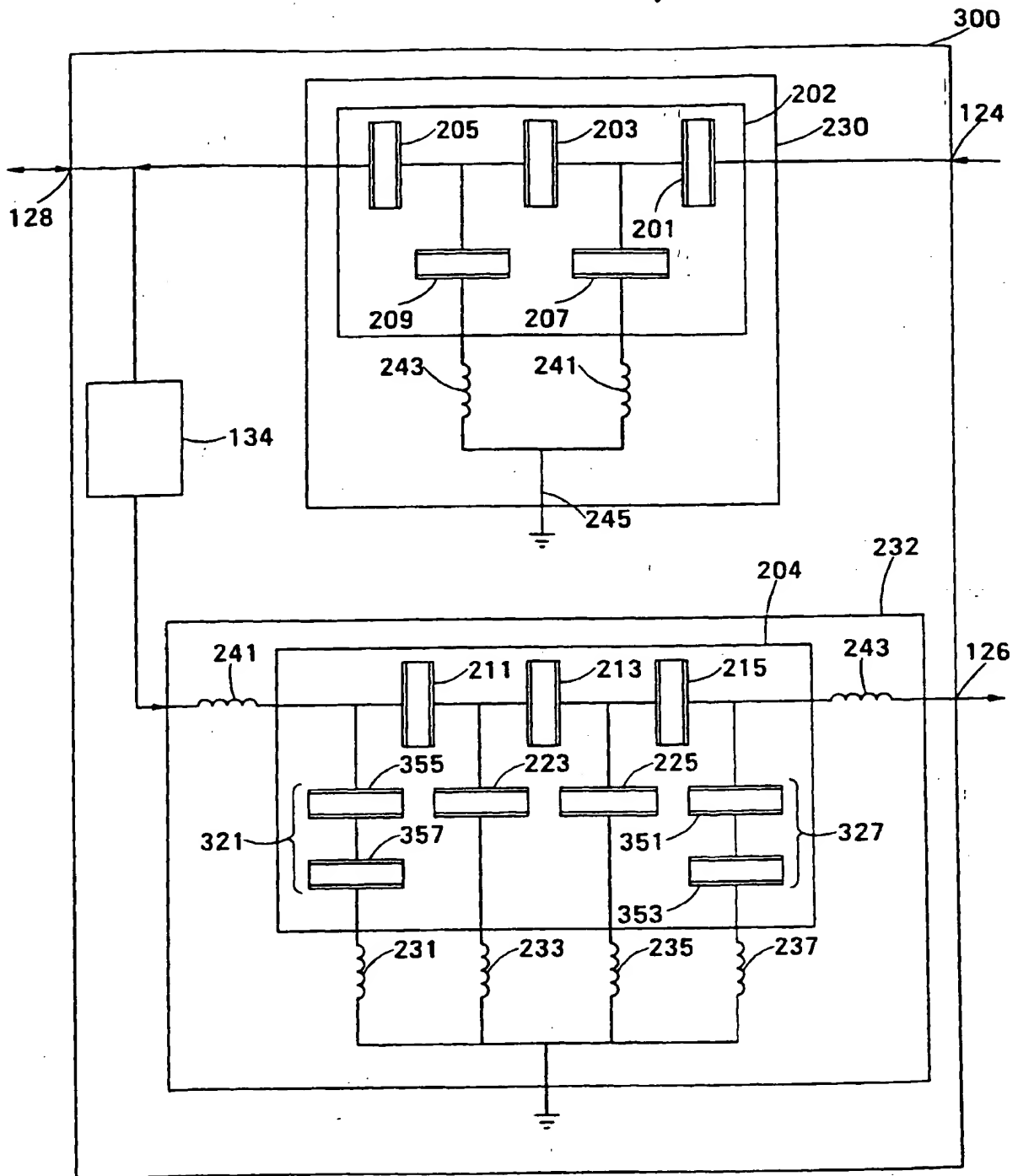


FIG.7